The Training of Teachers.—Interim Report of the Committee, consisting of the BISHOP OF HEREFORD (*Chairman*), Mr. J. L. HOLLAND (*Secretary*), Professor H. E. ARMSTRONG, Mr. OSCAR BROWNING, Miss A. J. COOPER, Mr. ERNEST GRAY, *and* Dr. H. B. GRAY.

THE Committee recognise that the problem of the training of teachers is at least as pressing in South Africa as it is in England at the present time; but local conditions are entirely different, and a Report prepared from the standpoint of English education would be of little assistance to South African administrators and teachers in the solution of their own particular training problem. Moreover, the time at the disposal of the Section for the discussion of Reports will be exceedingly short, and no adequate discussion will be possible. Under these circumstances, therefore, your Committee propose to make their formal Report at the York Meeting of the Association next year, and in order that they may be able to do so they respectfully request the Council of the Association to reappoint them for a further year.

On the Origin and Progress of Geodetic Survey in South Africa, and of the African Arc of Meridian. By Sir DAVID GILL, *K.C.B., F.R.S.*

[Ordered by the General Committee to be printed *in extenso*.]

[PLATES II. AND III.]

THE first geodetic operation in the southern hemisphere was that of the Abbé de la Caille, who, in 1752, measured an arc of the meridian 1° 13′ 17″ in length.

The result was anomalous, as apparently showing, by comparison with arcs measured in the northern hemisphere, that in the southern hemisphere the earth's polar radius is greater than its equatorial radius.

Improbable as this result appeared, La Caille's reputation for accuracy stood so high that a definitive settlement of the question was necessary.

The work of revision was undertaken by Mr. (afterwards Sir Thomas) Maclear, His Majesty's Astronomer at the Cape. After spending much labour in satisfactorily identifying La Caille's points of observation, Maclear connected them by a chain of triangulation which he extended southward to Cape Point and northward to Koeberg and Vogel Klip, including La Caille's four principal points.

He could not identify the terminal points of La Caille's base, but he measured a new base-line, 8·1 miles in length, nearly in the site of La Caille's base, and connected it with the points of his own and La Caille's triangulation. The measurement of the base was begun on October 30, 1840, and with continuous work it was completed on April 3, 1841. The measurement of the angles of the triangulation was begun in October, 1841, and the field-work, including the astronomical observations, was completed in March, 1848.

A full account of the work, edited by Sir George Airy, was published

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in two volumes, by order of the Lords Commissioners of the Admiralty, in 1866. Maclear's arc has an astronomical amplitude of 4° 37′ in latitude, and proves, within moderately narrow limits, that the form of the earth in the southern hemisphere is similar to that in the northern hemisphere.

The astronomical amplitude of La Caille's arc proved to be very nearly correct, but a large local disturbance of the direction of gravity at La Caille's northern station, amounting to more than 8″ of arc, accounted for the greater part of the apparent error of his work.

Nothing in the way of further systematic accurate triangulation was done in South Africa till 1859, when a triangulation of the southern coast of Cape Colony and British Kaffraria was set on foot, the Colonial Government being urged thereto by the demands of the Admiralty for the accurate determination of points on the coast-line in connection with the hydrographic survey which they were about to undertake, in order to correct the then very inaccurate and defective state of the charts of the coast. It was evident also that such a survey would furnish means of better connecting the detached property surveys through that part of the Colony. The work was entrusted to Captain Bailey, R.E., aided by one sergeant and thirteen rank-and-file of the Royal Engineers, five of whom were selected from the Ordnance Survey of England. The cost of the work was borne by the Colony ; it was begun in 1859 and concluded in 1862. The party embarked at Algoa Bay in the 'Waldensian,' *en route* for England. The vessel struck upon the rocks off Struys Point and became a total wreck. On board were the instruments, drawings, original observation books, with full abstracts, calculation books of every kind, all complete in every respect. They were all lost, and have never been recovered. Fortunately, copies of 'abstracts of angles' had been supplied to the Admiralty Surveyor engaged on the Coast Survey, other abstracts of angles with a diagram to the Surveyor-General in Cape Town, and from these and sundry copies sent to the Government of British Kaffraria and to private individuals an account of the work was compiled by Captain Bailey, and printed in a report presented to the Cape Parliament in 1863.

Soon after appointment to my present position at the Cape in 1879 I began to study the general question of the geodetic survey of South Africa. The traditions of my office appeared not only to justify, but to demand, that some portion of my time and attention should be devoted to this work. Sir Bartle Frere was then Governor of the Cape Colony and High Commissioner for South Africa.

From his experience of administration in India His Excellency thoroughly realised the advantages and the necessity for accurate survey, and the true economy of basing all future surveys upon a principal triangulation of such accuracy that its results might be considered definitive for all future time, and he gave my recommendations his strongest support.

These recommendations embraced a plan for a gridiron system of chains of principal triangulation extending over Cape Colony, the Orange Free State, Natal, and the Transvaal.

The political and financial situation in the Cape Colony at the time rendered it difficult for Ministers to take action during the session of 1880. But soon afterwards I had, through Sir Bartle Frere's kindness, the opportunity of meeting Sir George Pomeroy Colley, when His Excellency

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passed through Cape Town on his way to resume his governorship of Natal. In October 1880 I visited Natal as the guest of Commodore (now Admiral of the Fleet) Sir Frederick Richards, on his flagship, H.M.S. 'Boadicea,' in order to make preliminary experiments connected with the telegraphic connection of the longitudes of Aden and the Cape of Good Hope, and to further discuss with Sir George Colley the steps which should be taken in connection with the proposed survey. The result was that Sir George Colley took immediate steps to forward the project by addressing a message to the Legislative Council proposing to place a sum of 2,000*l.* on the estimates of 1881 for the initial expenses of the proposed operations, 'the expenditure to be contingent on the Cape Government undertaking to join in the proposed survey and bear its share of the general expenses connected with it.' One of the last documents addressed by Sir George Colley to the Legislative Council was a message of thanks for their reply to the above proposal; this message was dated December 21, 1880. A few days afterwards Sir George Colley left his seat of Government, never, alas! to return.

But it was not until I again visited Natal in August 1881, in connection with the Cape-Aden longitude operations, then in progress, that further advance was made. I took advantage of the opportunity to re-open the survey question, with the result that Colonel Mitchell (afterwards Sir Charles Mitchell, G.C.M.G.), who was then administering the Government of the Colony of Natal, decided to write to the Secretary of State, asking that the War Office might be applied to for the services of a captain and subaltern of Royal Engineers, with a party of non-commissioned officers and men, to begin the survey, and I was requested to prepare the specifications for the necessary instruments. Finally, in January 1883 I succeeded in arranging an agreement between the Governments of the Cape Colony and Natal to undertake the principal triangulation of both colonies as a joint work.

A detachment of Royal Engineers, consisting of Captain Morris, R.E. (now Colonel Morris, C.B.), Lieutenant (now Lieutenant-Colonel) Laffan, R.E., and fourteen non-commissioned officers and men, finally reached Durban in June 1883, and work was at once commenced by selecting, laying out, and measuring the base line in Natal. The field-work of the geodetic survey of the Cape Colony and Natal was completed in October 1892, and the results, including a rediscussion of Maclear's triangulation, were published and presented to the Cape Parliament in 1896. The completion of this work enabled me to carry out a complete re-reduction of Bailey's survey, as a complete chain of Bailey's best triangles was included in the work of the geodetic survey. Many errors in Bailey's published work were detected, and the whole was reduced to systematic agreement with the geodetic survey. The results form vol. ii. of the 'Geodetic Survey,' which was published in 1901.

The details of both works will be referred to later on. The main object to be kept in view was how to extend these operations in such a way as best to increase their geodetic value. In vol. i. of the 'Geodetic Survey' just mentioned (p. 157) I wrote on this point as follows:—'Looking forward to the practical and possible progress of geodesy, the question may be asked, *Should not the progress made in geodetic survey in South Africa be regarded as the first step in a chain of triangulation which, approximately traversing the thirtieth meridian of east longitude, shall extend continuously to the mouth of the Nile?*'

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On the immense importance of the proposed work as a geodetic operation it is unnecessary to dwell; the measurement of an arc of meridian 65° in amplitude would be a gain to geodesy so vastly important as alone to justify its inception.

But this is not all. By an additional chain of triangles from Egypt along the coast of the Levant and through the islands of Greece the African arc might be connected with the Roumanian and Russian arc, so as to form a continuous chain of 105 degrees in amplitude, extending from Cape Agulhas to the North Cape—the longest arc of meridian measurable in the world.

This object I have ever since constantly kept in view, and I have lost no opportunity of forwarding it.

Meanwhile, during the later stages of the field-work in Cape Colony and Natal, questions connected with the delimitation of the boundary between British and German territory in S.W. Africa had sprung up. That boundary is the subject of an agreement between the Governments concerned which was signed at Berlin in July 1890. It is defined to the south by a line commencing at the mouth of the Orange River, and ascending the north bank of that river to the point of its intersection by the 20th degree of east longitude, and, running then northwards along the meridian to the point of its intersection by the parallel of 20° south latitude, then eastward along that parallel to the point of its intersection by the 21st degree of east longitude, and thence northwards to the point of its intersection by the parallel of 18° south latitude.

Mr. Bosman had executed a chain of triangles from the neighbourhood of Vryburg westwards to the 20th meridian. This chain rested on a base line measured by Major Laffan, of which he also determined the orientation and the latitude and longitude of one of its extremities by astronomical observations, exchanging telegraphic signals for the latter purpose with the Cape Observatory. It should be mentioned to Mr. Bosman's credit that, although his work was paid for by the Bechuanaland Government at the tariff rates of secondary survey, Mr. Bosman made it his ambition to render the work fit for incorporation as an integral part of the geodetic survey. He procured a 10-inch theodolite at his private cost, and came to the Observatory for practical astronomical training, and he made a rigorous least square solution of the complex figures of which some parts of the chain were composed.

The work of Bosman and Laffan practically settled the position of the 20th meridian in the neighbourhood of the Orange River, and as far northwards as Reitfontein; but administrative difficulties soon arose further northwards, where there appeared to be an uncertainty of 18 or 20 miles as to the true position of the 20th meridian.

A temporary settlement of outstanding difficulties was made by Germany agreeing to withdraw from certain points near the boundary in dispute, and Great Britain undertaking that Bosman's triangulation should be extended northwards to the 22nd degree of south latitude.

Matters were in this state of friendly suspense when I visited England in 1896, and was consulted by the Colonial Office as to the means necessary to carry this promise into effect.

I then pointed out that from Reitfontein (the northern point of Mr. Bosman's survey) the 20th meridian crossed the Kalihari Desert, a country so flat and waterless that it would be difficult, if not impossible, to triangulate it. If, therefore, the triangulation had to be extended

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northwards, it would have to be carried through German South-West Africa, and it was unreasonable to expect that a work which would thus be of such advantage for the survey of German territory should be carried out entirely at British expense. I was accordingly instructed to proceed to Berlin to represent these views, and endeavour to come to some provisional agreement with the Foreign Office there on the lines above indicated.

The result of that mission was a joint proposal that Bosman's triangulation should be connected at both its eastern and western extremities with the geodetic survey of Cape Colony and continued northwards to the 22nd parallel of south latitude, thence along that parallel to the 21st degree of east longitude, and for a short distance northwards along the latter meridian. The cost of the survey north of Reitfontein to be equally divided between the Governments concerned.

Major (afterwards Lieut.-Colonel) Laffan, R.E., was appointed English Commissioner, and Lieutenant Wettstein German Commissioner, and the direction of the work was placed in my hands by both Governments concerned.

Lieutenant Wettstein at a later stage of the work was replaced by Lieutenant Doering.

The Commission assembled at Reitfontein, Gordonia, in November 1898. The Commissioners encountered the greatest obstacles in their work on account of the difficult and waterless character of the country—in fact some of the trig. points were forty miles distant from the nearest water supply; in other places much time and labour were required to clear trees and scrub, and the work was not brought to a close till October 1903.

Meanwhile Mr. Alston was employed by the Government of Cape Colony in connecting the eastern and western extremities of Bosman's triangulation with the geodetic circuit in Cape Colony. This work was completed in 1900.

Meanwhile, also in 1894, I urged on the late Cecil Rhodes the great scientific and practical value of commencing geodetic work in Rhodesia, and of the possibility of that work becoming part of the greatest arc of meridian in the world. Such an arc would also form a basis for the co-ordination of all detached surveys through a most important and still unsurveyed part of Africa, and be a fit precursor of his great scheme for a Cape to Cairo railway.

Mr. Rhodes was very sympathetic, but declared that Rhodesia was in the first place in need of roads, bridges, and other essential works; that he felt its resources must first be directed to these objects, but in the course of two or three years he hoped to set the work on foot. When, later (in 1897), Earl Grey as Administrator of Rhodesia, on my strong representation, sanctioned the commencement of the work, Mr. Rhodes not only took a deep interest in it, but when it had nearly reached the Zambesi he promised that funds would be provided to carry it to Lake Tanganyika. The field-work in Southern Rhodesia was carried out under Mr. Alex. Simms, formerly a computer at the Cape Observatory, who had there qualified as a surveyor, and who is now in charge of one of the field-parties engaged in the geodetic survey of the Transvaal and Orange River Colony. Time does not permit a description of the many difficulties encountered in the work on account of rains, smoke of grass fires, &c., which left only a few months available in each year for field-work.

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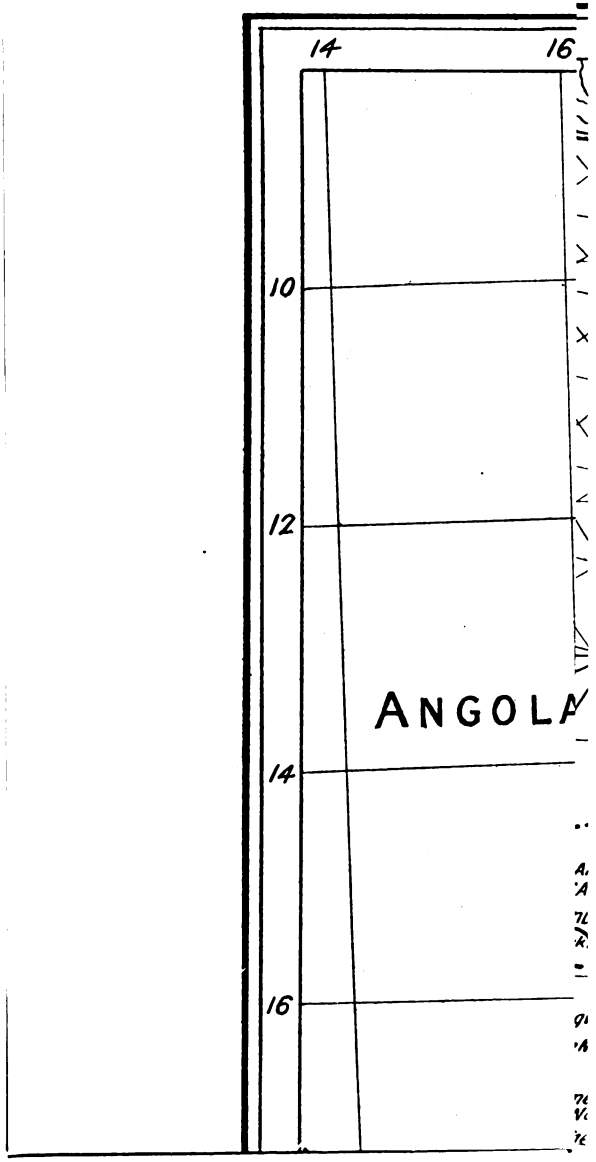

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Illustrating Sir David Gill's Paper on the Origin and Progress of Geodetic Survey in South Africa, and of the African Arc of Meridian.

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The work was suspended during 1902 on account of the war, and recommenced in 1903. I selected Dr. Tryggve Rubin as officer in charge of the work in Northern Rhodesia. He had been a member of the Swedish-Russian expedition for measurement of the Spitzbergen arc of meridian in the summer of 1901, and was leader of the expedition which completed that work in 1902. After residence for three weeks at the Cape Observatory he sailed for Chinde on April 29, 1903. He was joined by Mr. Tyrrell McCaw as chief assistant, who sailed from the Cape for Chinde on October 5 of the same year. There remained several points requiring occupation south of the Zambesi, and some others had to be re-selected, as further reconnaissance had shown them to be unsuitable for the northward extension. Dr. Rubin found, as Mr. Simms had found, extraordinary difficulties presented by haze, smoke, and heavy rains, and much of the first year was occupied with work connected with the Anglo-Portuguese boundary. Dr. Rubin's last report brings his statement of its progress up to April 1905.

In July 1902, during a visit to Lord Milner, then Governor of the Transvaal and Orange River Colony and High Commissioner for South Africa, I submitted plans and proposals for an ordnance survey of these Colonies. The original desire of Lord Milner was to have the topography of the country carried on *pari passu* with the principal triangulation, or, rather, to immediately follow the latter work in localities where maps were most urgently wanted. But in consequence of a proposal of the War Office for the formation of a central office for the execution of a topographic survey of South Africa, to which all South African Colonies were to contribute, I urged that the principal triangulation of the Transvaal and Orange River Colony should be first of all executed, in order to bring up their state of survey to a level with that of the Cape Colony and Natal.

That course was adopted, and the work has been in steady progress ever since, under the energetic directorship of Colonel Morris, R.E., C.B., pressure of other work having compelled me to limit my offices to those of scientific adviser.

So much for the history of the work. Let us now look at the results.

The large map Plate II. shows the whole of the triangulation accomplished in South Africa ; the different divisions of the work will be sufficiently evident from their geographical position.

Although the whole of the triangles shown in the Transvaal and Orange River Colony have been selected and beaconed, the whole have not yet been completely measured. Diagrams 1 and 2, Plate III., show the chains which have been completed and reduced in the Cape Colony, Transvaal, Orange River Colony, and Natal, with the exception of the astronomical observations at the points to which no figures are attached. For these points the astronomical observations have been made, though not yet reduced. The whole of the Bechuanaland and Damaraland triangulation, and its connection with Maclear's arc, and the triangles near Kimberley have also been reduced. The survey in Southern Rhodesia has been completely reduced.

In Rhodesia the two northern triangles have not been observed, or, rather, the details of their measurement have not yet reached me, but the rest have been preliminarily reduced for the purposes of the present paper.

The following are the base lines which have been measured, and from the following table it will be seen that they control, more or less

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directly, arcs of meridian, and they are therefore given in the order of these arcs, reckoning from west to east :—

Along	Name of Base	Latitude	Length. Feet	Measured with
19° E. Long.	Zwartland Base	33°	42819·065	Colby compensating bars
	S. Damaraland Base	—	Not yet measured	
	N. Damaraland Base	23	31029·97	Steel and brass Jäderin wires
25° E. Long.	Port Elizabeth Base	34	6000·000	Troughton & Simms steel bars
	Kimberley Base	28½	5999·185	Do. do.
	Ottoshoop Base	25½	57212·39	Nickel steel Jäderin wires
28° E. Long.	Wepener Base	30	71048·14	Do. do.
	Kroonstad Base	28	64919·67	Do. do.
	Ottoshoop and Belfast Base	26	See footnote	—
The great Meridian Arc along 30° E. Long.	Natal Base	29½	10800·457	Troughton & Simms steel bars
	Belfast Base	25½	62316·92	Nickel steel Jäderin wires
	Houts River Base	23½	—	Do. do.
	Inseza Base	20	62019·673	Steel and brass Jäderin wires
	Gwibi Base	17½	71165·270	Nickel steel and steel Jäderin wires
	Loangwa Base	15	57087·61	Nickel steel Jäderin wires.

The northern side of this arc is checked both by Ottos-hoop and Belfast base.

With exception of the first bases, measured by parties who used the Jäderin apparatus for the first time – *i.e.*, on the Inseza and North Damaraland bases—the probable error of base measurement is about 1 : 1,000,000. I estimate the uncertainty of the length of the Inseza and North Damaraland bases at 1 : 100,000.

The chief errors do not lie in the discordances of the repeated measurements of the base, but in the standardisation of the wires. But when the most complete methods are taken for standardising the wires, the chief source of error is the error of the absolute length of the standard bar, which cannot be relied upon, even after the most rigorous comparison, within less than 1 : 1,000,000. Full details of the basis of these conclusions are published in Vol. i. of the 'Geodetic Survey of South Africa,' with reference to the bases measured with the Troughton & Simms apparatus, and show the accidental probable error of measurement to be from 1 in 3 to 5 millions.

In regard to the Gwibi base, which enters into the great arc along the 30th meridian, having regard to the fact that the standardisation of the wires employed was carried out not on the field, but at the Cape Observatory, before and after the base measurement, the following particulars may be given :—

In the centre of the base-line site a ground standard of 400 yards

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was laid down. Its terminals were marked by fine holes in brass blocks, fixed on concrete pillars 2 feet square and 4 feet deep, founded on rock.

Each pair of wires was compared a number of times on November 3, 4, and 5 with the 400-foot ground standard before measurement of the base, and again on December 22 and 24 after measurement of the base.

The length of the standard base for the measurements in November was computed from the results of the Cape comparisons in the preceding August and September, and those of December from the Cape comparisons in the following January.

The results are given in the following table, in three columns, for comparison—

a. From all measures.

b. From measures with wires not used in the base work.

c. From measures with the old wires only, and excluding the later measure with the C, D pair (D having been used on the base).

Length of 400-*foot Ground Standard.*—A.

1900	Wires	*a*	*b*	*c*
		mm.	mm.	mm.
November 3, 4, and 5, with lengths derived from Cape comparisons in August and September	P and PP	121923·66	121923·66	—
	Q „ D	24·81	24·81	—
	A „ B	23·20	23·20	121923·20
	C „ D	23·20	23 20	23·20
	E „ F	23·54	23·54	23·54
December 22 and 24, with lengths derived from Cape comparisons in January 1901	P „ PP	25·06	—	—
	Q „ D	25·08	—	—
	A „ B	23·53	23·53	23·53
	C „ D	23·82	—	—
	E „ F	23·17	23·17	23·17
Means	—	121923·91	121923·59	121923·33
Probable error . .	—	± 0·16	± 0·15	± 0·06

The wires A, C and E were of steel.
„ B, D and F „ brass.
„ P and Q „ nickel steel *invar*.
„ PP „ nickel steel having a coefficient of expansion somewhat like that of brass.

The pairs of wires P, PP and Q, D were alone used for measurement of the base, but they were compared with the 400-foot ground standard before and after measurement of each section of the base, with the following results, when corrected to the temperature at which both wires have the same length (Jäderin method), assuming the 400-foot ground standard (S) to be constant in length.

1900	P, PP	Q, D
	mm.	mm.
November 3, 4, 5	$\frac{1}{6}$S. − 3·61	$\frac{1}{6}$S. − 3·94
„ 14, 15, 16 . . .	− 3·80	− 3·96
„ 27, 28	− 3·76	− 3·95
December 5	− 3·82	− 4·02
„ 17, 18	− 4·01	− 4·19
„ 22, 24	− 4·28	− 4·35

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It will be seen from this and the preceding table that the hard work of base measurement has a tendency to induce molecular change in the wires, and that the wires left at comparative rest give more consistent results for the standard ground base (see column *c* of preceding table). It is also evident that new wires have a tendency to contract.

This latter point will be more evident from the following table of the lengths of the wires at 70° F. at the different epochs when their absolute lengths were determined at the Royal Observatory.

—	A Steel	B Brass	C Steel	D Brass	E Steel	F Brass
	mm.	mm.	mm.	mm.	mm.	mm.
(1) April–May, 1898 .	24383·93	24386·23	24384·36	24386·18	24383·57	24385·94
(2) Oct.–Nov. 1898 .	82·65	85·67	84·17	86·04	82·57	85·42
(3) April–May, 1900 .	82·63	86·01	84·13	86·03	83·12	85·77
(4) Aug.–Sept. 1900 .	82·40	85·73	83·91	85·79	82·81	85·19
(5) Jan. 1901 . .	82·15	85·58	83·71	85·84	82·64	85·02

The wires P, PP and Q were only supplied in 1900.

(1) and (2) were the comparisons made before and after the measures of the Inseza base near Bulawayo, of which I give here no further details, as it does not enter into the great arc of meridian; (3) was an intermediate comparison; (4) and (5) the comparisons of the wires made before and after the measures of the Inseza base.

The length of the 400-foot ground standard was adopted from the mean of the measures with all the wires before and after the base measurement.

The adopted lengths of the measuring wires for each section of the base were the mean length derived from their comparison with the ground standard before and after the measurement of that section.

Each section of the base was measured both forwards and backwards by both wires. The following are the results :—

Section	By Wires P and PP	By Wires Q and D	Discordance
	mm.	mm.	
I. *a* . . .	1,646,525	1,646,530	1 in 329,000
b . . .	4,020,152	4,020,130	,, 163,000
II. . . .	3,144,434	3,144,433	,, 3,100,000
III. *a* . . .	3,530,470	3,530,492	,, 161,000
b . . .	1,595,383	1,595,382	,, 1,600,000
IV. *a* . . .	3,715,304	7,758,926	,, 431,000
b . . .	4,0136,40	—	—
	21,695 908	21,695,893	1 in 1,446,000

The adopted mean length is 21,695,901 mm.
71,181·419 feet.

I have gone into this detail in connection with the measurement of the Gwibi base because it is certainly the least accurate of the base lines that occur on the great arc of meridian,

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If we adopt instead of the result of column *a* (table A) that derived in column *c*, which may possibly, for reasons explained, be the more correct, we should obtain a shorter length by about 1 : 200,000; on the whole I am disposed to think that the probable error of the base is not much greater than that.

For measurement of the base lines in the Transvaal and Orange River Colony much better appliances were available. The steel-bar measuring apparatus was transported in all cases to the site of the base, and a 480-foot ground standard was measured before and after the measurement of each section of the base, both with the steel bars and the wires used in measurement of the section.

A large amount of time was devoted at Belfast to the training of the base-measuring staff, determining temperature coefficients of wires, and making experiments and tests of various kinds, so that a most effective working staff was created.

I feel certain it would be true economy in all future large geodetic operations to have a base-measuring staff first well trained, and to measure the bases so soon as the reconnaissance has been completed, and before the angles of the chain are definitively measured.

There have been five base lines measured in the Transvaal and Orange River Colony, of which the results are as follows :—

— —	No. of Sections	Total Length. Mètres	Probable Error.
			m.
*Belfast Base	9	18,994·027	± 0·009 = 1 : 2,423,000
Ottoshoop Base	8	17,438·178	·005 1 : 3,487,000
Wepener Base	6	21,655·280	·009 1 : 2,406,000
Kroonstad Base	4	19,787·341	·004 1 : 4,946,000
*Houts River Base	8	33,961·340	·005 1 : 6,792,000

Each section of the base was measured three times.
Those marked * occur on the great arc of meridian.

These probable errors of the total length of the base are derived from the differences of the three independent measures of each section, and include, therefore, the effect of the accidental errors of the measurement with the Jäderin wires, the errors of their comparison with the ground standard base of 480 feet, and the measurement of the ground base with the steel bars; *but they do not include* systematic errors due to imperfect knowledge of the absolute length of the steel bars, which may be 1 : 1,000,000.

The three independent measures of the Belfast base give—

18,994·027 mètres.
·077 „
·066 „

The Houts River base is on the arc of meridian north of Belfast, about 100 miles south of the Limpopo. The following particulars about its measurement may be taken to represent the accuracy that can be attained by the Jäderin method when properly employed.

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TABLE A.—*Length of 480-foot Ground Base Determined by Measurement with the Steel Bars.*

Date 1904	Temp. (F.)	Length of Base mm.
May 25	69	146308·75
„ 26	57	·71
June 2	71	·49
„ 7	59	·58
„ 13	70	·43
„ 18	59½	·68
„ 20	52	·83
„ 25	75	·59
„ 26	68	·77
„ 27	53	·68

TABLE B.—*Apparent Length of Measuring Wires from Comparison with 480-foot Base.*

Date 1904	Wire 1 mm.	Wire 3 mm.
May 26		24381·31
June 2	24380·74	—
„ 7	·77	—
„ 13	·75	—
„ 18	·76	—
„ 20	·77	—
„ 25	·75	—

The wire 3, used in previous bases, met with an accident on May 27; wire 1 was substituted.

Each section of the base was measured three times, viz., once *forward*, then *backward*, finally *forward*. The results are given below.

The separate lengths derived from each measurement are given below :—

TABLE C.—*Measured Lengths of Sections of the Houts River Base, after correction, from comparison with Standard Base.*

Section	mm.	Section	mm.
I. . . 180l +	418·1 423·4 437·0	V. . . . 192l −	410·9 417·2 416·9
II. . . . 200l +	59·6 60·6 68·3	VI. . . . 144l +	419·7 411·6 410·0
III. . . . 180l +	91·7 85·0 87·7	VII. . . . 177l −	864·4 865·1 859·2
IV. . . . 220l +	13622·7 13621·7	VIII. . . . 130l −	5330·1 5332·6 5334·4

where l = 24380·0mm.

The measurements of the base line on the banks of the Loangwa, in Northern Rhodesia, are not yet definitively reduced. The base itself is 17,400 mètres in length; the difference between the two measures was 49 millimètres.

As full details of all the base lines measured with the Troughton & Simms steel bars are given in Vol. i. of 'The Geodetic Survey of South Africa,' I need not go here into further detail, but merely state that their

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For Cape Colony and Natal.

Abstract of Triangular Errors.

Observer	Portion of Chains	No of Δ^s	Limit of Errors of Triangles									Probable Error of a Single Angle
			" 0·0 to 0·5	" 0·5 to 1·0	" 1·0 to 1·5	" 1·5 to 2·0	" 2·0 to 2·5	" 2·5 to 3·0	" 3·0 to 3·5	" 3·5 to 4·0	" 4·0 to 4·5	
	Troughton & Simms 18-*inch Theodolite.*											
M.	Zwaartkop, Newcastle	19	8	3	4	3	—	—	1	—	—	± 0·492
M.	Zwaartkop, Griqualand	15	7	3	3	—	2	—	—	—	—	± 0·394
M.	Natal base extension	30	12	4	7	2	3	2	—	—	—	± 0·502
L.	Griqualand Triangulation	36	14	3	9	6	—	3	1	—	—	± 0·522
		100	41	13	23	11	5	5	2	—	—	± 0·493
	Repsold 10-*inch Theodolite.*											
M.	King William's Town to Port Elizabeth	8	3	3	1	1	—	—	—	—	—	± 0·362
M.	Port Elizabeth base extension	13	8	4	1	—	—	—	—	—	—	± 0·213
M.	Port Elizabeth to Caledon	22	8	7	5	1	—	—	1[1]	—	—	± 0·427[1]
M.	Port Elizabeth to Kimberley	37	18	10	6	3	—	—	—	—	—	± 0·314
M.	Kimberley base extension	25	10	8	6	1	—	—	—	—	—	± 0·324
M.	Hanover to Calvinia	23	11	8	3	1	—	—	—	—	—	± 0·294
P.	Tie Chain N. of Mossel Bay	6	4	2	—	—	—	—	—	—	—	± 0·224
		134	62	42	22	7	—	—	1	—	—	± 0·326
Various	Sir T. Maclear's Δ^s employed in the geodetic circuit	13	5	2	3	1	1	—	1	—	—	± 0·622

M. = Colonel Morris, R.E. L. = Lieutenant Laffan, R.E. P. = Mr. R. Pillans.

[1] This triangle has one line which crosses an arm of the sea, and its error is obviously abnormal. If this triangle is rejected, the probable error of an observed angle in the arc Port Elizabeth-Caledon becomes +0″·329, and the general probable error of an angle observed with the Repsold theodolite becomes ± 0″·306.

accidental errors of measurement are certainly considerably less than the uncertainty of the determination of the lengths of the bars—which uncertainty is of the order of 1 : 1,000,000.

With regard to the accuracy of triangulation, the probable error of

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measurement of the angles of the triangles has been computed from the formula

$$\cdot 6745\sqrt{\frac{\Sigma\Delta^2}{3N}},$$

where $\Sigma\Delta^2$ is the sum of the squares of the triangulation errors, and N is the number of triangles.

For the geodetic survey of the Cape Colony and Natal the preceding table exhibits the limits of error of the triangles in excess or defect of $180° + \epsilon$.

The probable error of a single triangle in Bosman's triangulation is as follows :—

Section I.	± 1″·41	Very flat, arid country, sides 3 to 8 miles.
,, II.	± 0″·92	,, ,, ,, ,, rather longer sides.
,, III.	± 0″·66	Rolling country, longer sides.
,, IV.	± 0″·42	

In Mr. Alston's connections of the eastern and western extremities of Bosman's arc with the geodetic survey the probable error of an angle was :—

For the Eastern connection ± 0″·58
,, ,, Western ,, ± 0″·57.

In the arc through Damaraland the distribution of triangular errors is as follows :—

—	Limiting Values of Errors of Triangles								
	″ 0·0 to 0·5	″ 0·5 to 1·0	″ 1·0 to 1·5	″ 1·5 to 2·0	″ 2·0 to 2·5	″ 2·5 to 3·0	″ 3·0 to 3·5	″ 3·5 to 4·0	″ 4·0 to 4·5
No. of Triangles	52	48	34	19	18	17	3	2	1

From the original errors of closure of the 194 separate triangles the probable error of an angle was found to be ±0″·59.

In the Transvaal, Orange River Colony, and Rhodesia, so far as the results are before me, the triangular errors and probable errors of a single angle are as follows :—

Abstract of Triangular Errors.

Observers	Portion of Chains	No. of Triangles	Limit of Errors of Triangles					Probable Error of a Single Angle
			″ 0·0 to 0·5	″ 0·5 to 1·0	″ 1·0 to 1·5	″ 1·5 to 2·0	″ 2·0 to 2·5	
G.	Belfast-Natal . .	29	15	8	4	—	2	± 0″·33
G.	Belfast-Ottoshoop . .	28	14	9	2	2	1	± 0″·35
S.	Pretoria-Cwecweni .	63	25	26	10	2	—	± 0″·30
G.	Natal-Kroonstad . .	10	6	4	—	—	—	± 0″·19
G.	Kroonstad-Kimberley .	18	10	7	1	—	—	± 0″·23
L.	Kimberley-Ottoshoop .	57	19	18	12	7	1	± 0″·33
		205	89	72	29	11	4	± 0″·33

S. = Mr. Alex. Simms. G. = Captain Gordon, R.E. L. = Captain Leys, R.E.

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In Northern Rhodesia Dr. Rubin's results, so far, appear to be of like accuracy with those obtained by Mr. Simms in Southern Rhodesia.

But now with regard to the nine crucial tests given in Diagrams Nos. 1 and 2, Plate III..

If it were possible to measure all the angles of a triangulation without error, and base lines without error, it is clear that if the length of any one base was calculated from any other base as origin through any intervening chain of triangles, we should obtain a length of the base by computation which would agree precisely with that of its measured length. As all human operations are fallible, this agreement never occurs except as a matter of chance; and, as the operation of triangulation is necessarily much less accurate than that of base measurement, the discordance between bases compared through intervening triangles is generally far greater than the probable errors of base measurement.

On this account it is usual to consider the base lines as free from error, and to compute by least squares the corrections applicable to the angles of the triangles which are necessary to bring about an agreement between the measured and computed lengths of all the base lines. Colonel Morris has kindly communicated to me the results of the preliminary computations made for intercomparing the bases measured in Cape Colony, the Transvaal, Orange River Colony, and Natal, with the exception of the Limpopo, or Houts River base, the triangulation connecting which with the Belfast base is not yet completed.

Diagram No. 1.

Comparison of Measured Lengths of Bases with Lengths computed from the Port Elizabeth Base (produced).

Base	Through Chain	Approx. Length of Chain	Approx. Length of Base	Apparent Error of Base	Ratio
		Miles	Feet	Feet	
Zwartland . .	1	500	42,819	−1·37	1 : 31,250
Kimberley . .	2	400	14,760[1]	−0·50	1 : 29,750
,, . .	3	600	,,	−0·50	1 : 29,750
,, . .	1 + 3	1,100	,,	−0·94	1 : 15,620
,, . .	9	1,150	,,	−0·45	1 : 32,650
Natal . . .	4	400	10,800	−0·26	1 : 41,770
Belfast . .	5	700	62,316	−0·98	1 : 63,870
Ottoshoop . .	6	950	57,212	−1·88	1 : 30,380
Kroonstad . .	7	1,050	64,920	−1·92	1 : 33,930
Wepener . .	8	1,200	71,048	−1·28	1 : 55,680

[1] This refers to the base prolonged by triangulation from 6,000 feet, directly measured.

It is very remarkable that these comparisons agree in showing all the other bases are apparently shorter than the Kimberley base, and it seems impossible not to conclude that there is some undiscovered source of error in the Kimberley base, although it is hardly possible that the base itself is really six inches too long, as this comparison would appear to show. It is more likely that the error has been produced by a grazing line or lines in the extension of the base; although the residuals in the angles of the quadrilateral figures by which the base was prolonged show extremely small residuals, for one cannot imagine that the measured part of the base

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(6,000 feet) can be 2½ inches in error, seeing that the largest difference between the forward and backward measure of any of its eight sections was only $\frac{3}{100}$ of an inch.

Taking now the Belfast base as standard, and comparing it through various independent circuits with the other bases, we get the following results, which are in much better agreement :—

Diagram No. 1.

Comparison of Measured Lengths of Bases with Lengths computed from Belfast Base.

Base	Through Chain	Approx. Length of Chain	Approx. Length of Base	Approx. Error of Base	Ratio
		Miles	Feet	Feet	
Ottoshoop . .	6–5	250	57,212	–0·99	1 : 57,900
Kroonstad . .	7–5	350	64,920	–0·90	1 : 72,380
Wepener . .	8–5	500	71,048	–0·16	1 : 434,300
Natal . . .	4–5	300	10,800	–0·09	1 : 120,600
Port Elizabeth .	5	700	17,058[1]	+0·27	1 : 63,870
Zwartland . .	1–5	1,200	42,819	–0·70	1 : 61,160
„ . .	9–5+3	1,250	„	+0·73	1 : 58,690
Kimberley . .	9–5	450	14,760[1]	–0·22	1 : 66,810
„ . .	2–5	1,100	„	–0·26	1 : 55,680

[1] These refer to the bases prolonged by triangulation; the measured distances were 6,000 feet on both bases.

But besides the discordances of bases when computed through intervening triangulation from one to another, in order to attain geometrical harmony we must also satisfy the condition that the circuits shall close harmoniously; that is to say, the terminal point of any side of any triangle in the chain, when computed in any direction through the chain, shall be exactly reproduced in latitude and longitude, and the side in length and azimuth.

The discordances are given in the following tables, illustrated by Diagram 2.

Closure on Lines.

Circuit	Circuit Junction	Approximate Length	Log. Discordance of Side	Ratio
		Miles		
(*a*) 1+2	Bruintjes-Hoogte–Kagaberg .	1,100	·0000132	1 in 32,900
1	Bushman's Berg–Elandsberg . .	700	·0000084	1 in 51,450
7	Drakensberg – Salt Lake . . .	650	·0000010	1 in 434,300
(*b*) 5+7	Lubisi Xuka . .	1,100	·0000031	1 in 140,000
(*c*) 3+4+5+7	Scholtz Kop–Tarantal Kop . .	1,500	·0000029	1 in 150,000

(*a*) This is equivalent to the closure on Kimberley base through chains 1+3 and 2 (Diagram 1).

(*b*) Part of the temporarily adjusted chain for the closure on the Natal base.

(*c*) The temporarily adjusted chains for closure on Kimberley and Natal bases enter into this circuit; otherwise the equation would be equivalent to the closure on the Kimberley base through chains 2 and 9 (Diagram No. 1).

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Closure in Latitude, Longitude, and Azimuth.

Circuit 1.

Terminal line: Kliprug–Spionberg II.

	Lat.	Long.	Az.
Right hand–Left-hand Branch	+0″·032	+0″·105	+0″·075

Circuit 2.

Terminal line: Canaryfontein–Elandsberg.

	Lat.	Long.	Az.
Right hand–Left-hand Branch	+0″·028	+0″·050	−4″·229.

In circuits 1 and 2 the errors of closure are those obtained after closure of bases.

Circuit 7.

Closure on Drakensberg–Salt Lake through north, west, south, east.

		Lat.	Long.	Az.
'Geodetic Survey,' Vol. i. *minus.*	Computed	+0″·021	+0″·060	−0″·43

Circuit 5+7.

Closure on Xuka-Lubizi through north, west, south.

	Lat.	Long.	Az.
'G. S.' Vol. i.—Computed	+0″·172	+0″·120	−1″·48.

Circuit 3+4+5+7.

Junctions at Scholtz Kop with Tarental Kop.
From Drakensberg ('G. S.' Vol. i.) to Scholtz Kop ('G. S.' Vol. i.)

	Lat.	Long.	Az.
('G. S.' Vol. i.)—Computed	+0″·048	+0″·044	−2″·78
Circuit 3, 4	+0″·266	−0″·076	−1″·30
Circuit 5	+0″·151	+0″·060	−1″ 05

It will be observed that the chains joining Hopetown and Wepener, Kimberley and Ottoshoop, Ottoshoop and Pretoria and Belfast with the Limpopo or Houts River base, are not yet completed, and therefore these circuits cannot be yet discussed. But enough has been done to show the high character of the work.

We turn now to the geodetic results.

Taking first of all arcs of meridian, and beginning from west to east, we have

The Arc near the Meridian of 19° *E. Long.*

This arc depends in the south on Sir Thomas Maclear's arc, part of which has been re-observed by Colonel Morris and entirely re-reduced to the gridiron system of the 'Geodetic Survey of Cape Colony'; then on Alston's triangulation to the Orange River, then on Bosman's triangulation along the 20th meridian to South Reitfontein, and thence northward to Latitude 22 South, through Damaraland, by the Anglo-German Boundary Commissioners, Laffan, Wittstein, and Doering.

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Authority	Longitude	Latitud	Astron. *minus* Geod. Lat.	Astron. *minus* Geod. Azimuth
	° ′	°	″	″
Sir T. Maclear : Cape Point . .	18 29	34 21	−0·04	—
,, Zwartkop (C.C.) .	18 27	34 13	−1·27	—
— Gill : Royal Observatory	18 29	33 56	+0·48	−5·92
Colonel Morris: Tygerberg . .	18 35	33 51	+1·98	−3·02
,, Robben Island .	18 23	33 48	+0·75	−7 06
Sir T. Maclear : Klipfontein (Sector Station) .	18 29	32 41	+7·42	—
,, Heerenlogements Berg . . .	18 35	31 58	−0·57	—
,, Kamies Sector Berg	18 8	30 21	+8·14	+1·09
,, North End (Sector Station) . .	18 33	29 44	+0·12	—
Mr. Bosman : Upington . .	21 14	28 26	−0·50	—
,, Vet Rivier . .	20 0	26 49	−0·96	−2·49
Col. Laffan : Reitfontein . .	20 2	26 44	+0·60	−2 89
Lt. Wettstein : Gibeon. . .	17 46	25 7	+0·77	−6·73
and Gill's Wald . .	18 47	22 57	−1·12	−4·80
Lieut. Doering : Oliphants Kloof .	20 5	22 11	+3·02	−4·02
Epukiro . .	20 57	21 55	−0·12	−3·61

The astronomical amplitude of the extreme stations of the arc is 12° 25′ 18″·39. The geodetic amplitude (Clarke's elements), 12° 25′ 18″·31.

This arc, properly speaking, rests on two base lines, viz., the Zwartland base, measured by Sir Thomas Maclear, and a base of which one of its terminals is the point Gill's Wald, measured by the Anglo-German Boundary Commissioners.

	Mètres.
The length of the latter base, computed through the long chain of intervening triangles from one of the sides of the geodetic circuit, is	= 9457·850
The directly measured length was	= 9457·440
Difference computed-measured is therefore	= 0·410
	or = 1 : 23·000

The geodetic amplitude of the arc has, however, been computed solely from the Zwartland base, and it would have been increased by about 0″·5 if the Commissioners' base had been taken into account. There is unmistakable evidence of strong local deviation of the direction of gravity at Klipfontein and Kamies Sector Berg, but, apart from these stations, if we divide the arc into groups we have the following results :—

—	No. of Stations	Mean Latitude	Astron. *minus* Geodetic
		° ′	″
Southern End of Maclear's Arc .	5	34 2	+0 38
Northern ,, ,, ,, .	2	30 51	−0·22
Southern End of Boundary Survey	4	26 31	−0·02
Northern ,, ,, ,,	3	22 22	+0·60

The reason why the northern base was not taken rigorously into account in the computations is, that it is desirable in so long an arc to measure at least one other base, say in the neighbourhood of Reitfontein,

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and it is only waste of time, therefore, to compute corrections to the chain, which will certainly have to be replaced by others at a later date.

The geodetic amplitude could be greatly strengthened by a direct connection southwards, across the Orange River, between the sides Spitzkopje-Karasberge-Sonnabende Hugel with the sides Naib-Agenys or Agenys-Eitjes of Alston's triangles. We may confidently rely on the scientific spirit of Germany to measure at least another base and increase the number of astronomical stations on this arc.

Arc near the Meridian of 26° E. Longitude.

This arc is at present incomplete, because the triangles connecting Kimberley and Ottoshoop are not yet measured. The geodetic latitudes will depend on two parallel chains of triangulation which unite at the northern part of the arc, and cover about 4° in longitude. The astronomical observations at some of the stations have not yet been reduced, and further astronomical stations are required at the northern end of the arc.

The results, however, are interesting as they stand.

—	Long.	S. Lat.	Astron. *minus* Geod. Lat.	Astron. *minus* Geod. Azimuth
	° ′	° ′	″	″
Cape St. Francis	24 46	34 10	+ 0·84	—
Buffelsfontein[1]	—	—	0·00	0 00
Port Elizabeth	25 37	33 58	− 7·37	−0·90
Coega Kop	25 37	33 46	− 7·90	—
Zuurberg	25 34	33 14	+10·96	—
Drivers Hill	26 42	33 17	+ 1·87	—
Berlin	27 37	32 53	+ 6·80	+0·53
Grassberg	24 29	32 51	+10 74	—
Lubisi	27 30	31 47	Not yet reduced	
Tafelberg	25 10	31 38	+ 0·32	—
Washbank Peak	27 30	31 12	Not yet reduced	
Hanover	24 26	31 4	− 0·01	—
Helvelyn	27 14	30 40	Not yet reduced	
Aasvogel Kop	27 5	30 14	Not yet reduced	
De Put	23 55	30 14	− 0 58	—
S. End Wepener Base	27 1	29 50	Not yet reduced	
N. End Wepener Base	26 59	29 37	Not yet reduced	Not yet reduced
Kimberley	24 43	28 38	− 1·57	+1·07
N. End Ottoshoop Base	25 53	25 33	− 4·45	+2·06

[1] Buffelsfontein is the origin of the latitudes and azimuths of the system. The accuracy of the arc when the connection between Kimberley and Ottoshoop has been completed will be very great, as practically five first-class base lines enter into the control of its geodetic amplitude, as well as an excellent gridiron system. The large local deviations of gravity (−7⅓″ near Port Elizabeth and +10½″ at Zuurberg and Grassberg) tend somewhat to diminish the value of the arc as a measure of the earth's mean curvature.

Great Arc along the 30th Meridian north of the Limpopo.

From the Limpopo northwards to the following triangles a gap exists, not yet filled, and the station Salisbury is taken as the new origin both for latitude and azimuth.

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Great Arc along the 30th Meridian south of the Limpopo.

——	Long.		Lat.		Astron. *minus* Geod. Lat.	Astron. *minus* Geod. Azimuth.
	°	′	°	′	″	″
Gwecweni	28	0	31	50	Not yet reduced	Not yet reduced
Umtata	28	45	31	36	+2·98	+0·52
Xuka	28	0	31	18	Not yet reduced	
Bendearg	27	55	31	2	,,	−1·37
Umtamvuna	29	57	30	44	+1·71	—
Durban	31	0	29	51	+2·19	—
Zwartkop	30	15	29	36	+1·32	—
Salt Lake	30	4	27	55	+6·1	—
Newcastle	29	56	27	46	+1·10	−3·33
Hermitage	29	20	27	40	Not yet reduced	
Vierfontein	28	40	27	32	,,	
Inkwelo	29	50	27	31	,,	
Kaalkop	29	5	27	30	,,	
Gemsbokberg	29	27	27	27	−6·3[1]	—
Johannesburg	28	6	26	3	−9·33	−1·14
S. End Belfast Base	30	2	25	40	−3·50	−2·60
Lange Kloof	29	57	25	31	−4·41	—
Mare's Kop	30	6	25	30	−2·77	—
N. End Belfast Base	30	22	25	29	−6·61	—

[1] From this point northwards to the Limpopo the observations have not been completed.

	——	Long.		Lat.		Astron. *minus* Geod. Lat.	Astron. *minus* Geod. Azimuth
		°	′	°	′	″	
Observed by Mr. Simm.	Inugu	28	24	20	30	−0·02	—
	Golati	28	36	20	29	+1·23	—
	M'Quilembegwe	28	45	20	26	−3·78	—
	Thabas Inyorka	28	41	20	19	+0·09	—
	Tsetsa	28	22	20	17	—	+1·34
	Bulawayo (Long Pt.)	28	35	20	9	−10·16	+0·72
	S. End Inseza Base	29	9	20	6	−2·75	—
	N. End Inseza Base	29	4	19	57	−3·52	−2·61
	Gwelo	29	50	19	28	+0·98	+0·26
	Iron Mine	30	22	19	19	−4·37	—
	Zontimba	30	13	19	16	−3·99	—
	Mahamara	30	17	19	5	−4·41	—
	Salisbury	31	2	17	50	0·00(origin)	0·00
	Marimba	30	50	17	47	−4·68	—
	Muneni	30	34	17	30	−5·43	—
	Baruka	30	6	17	19	−3·17	—
	Umvukwe	30	41	17	12	−7·38	—
	Manyangau or Inyangau	29	36	16	26	−9·70	+4·76
Observed by Dr. Rubin.	Msambamsou	30	0	15	53	−8·05	—
	Kapsuku	30	20	15	40	−6·17	—
	Machachetti	29	52	14	55	−2·35	—
	Mkokomo	30	36	14	37	—	—

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From these meridian arcs the results which appear to come out are :—

1. In the arc along the meridian of 19° east longitude the apparent curvature of the meridian between latitudes 22° and 35° corresponds very closely with that given by Clarke's 'Elements of the Figure of the Earth.'

2. Along the meridian of 26° east longitude, between latitudes 25½° to 34°, there appears to be a tendency for the astronomical amplitude to exceed the geodetic by perhaps 0″·1 per degree, but the great deviations of the plumb-line when one passes from the neighbourhood of the coast to the great mountain range immediately to the north obscures the conclusion.

3. This tendency seems still more strongly marked on the 30th meridian, both in the arcs to south and north of the Limpopo. But that point will be better determined for the arcs on the 26th and 30th meridian south of the Limpopo when the recently made latitude observations have been reduced, and when the arc north of the Limpopo has been carried to Tanganyika ; and still better when the gap between the Limpopo and the Rhodesian triangles has been filled and the Rhodesian arc can be reduced to the same origin as the rest of the geodetic survey.

It was my earnest hope to be able to announce to this meeting that the actual work of this connection had been begun. Captain Gordon, R.E., with a well-trained party, was in readiness to start under the orders of Colonel Morris, but no persuasions of mine could induce the Chartered Company to grant the necessary funds.

Only 1,600*l.* was required, which must be considered a very small sum, having regard to the scientific importance and practical value of the work.

I must admit that the British South Africa Company is loyally carrying out Mr. Rhodes's promise to me—viz., 'I will see that you get the money to carry this survey to Lake Tanganyika, and when you have got there, if the Transvaal has by that time carried its triangulation to the Limpopo, we will meet them there.'

But now that the principal triangulation of the Transvaal and Orange River Colony is nearly complete, and trained men were ready, almost on the spot, to make the connection, a like opportunity to do it so economically and so well is never likely to recur. I say this in justification of my urging the Company, at a time when money is scarce in South Africa, to undertake this work sooner than Mr. Rhodes had promised it would be done.

I do not propose to discuss a comparison between the astronomical and geodetic longitudes, because the data are as yet somewhat meagre, and it has been as yet impossible to organise a longitude campaign with elimination of personal equation and the final control which can only be attained by comparison of results derived through different lines of intercommunication. It is sufficient to say at present that, so far as they go, the longitudes agree better with Bessel's and the latitudes with Clarke's elements.

It remains to mention the services of those who have carried out the work.

First and foremost comes the name of Colonel Morris. To him, and almost entirely to the work of his own hands and eyes, we owe the observations in Cape Colony and Natal—ten years of strenuous service in the

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field and one year in office work, given with a singleness of purpose and a devotion and enthusiasm which are beyond praise. To his foresight is due the fact that no accident happened to mar the progress of the work, and to his tact the fact that he and his party were everywhere welcomed, and no objections were seriously raised to his entrance on farms or claims made for damage to property. The rapid progress and the high efficiency of the work in the Transvaal and Orange River Colony are the result of his great experience and administrative capacity.

The difficulties which must beset an international commissioner in another country than his own were overcome by the patience and tact of Lieut.-Colonel Laffan in the Anglo-German Boundary Survey, and high praise is also due to Lieutenant Doering, the German Commissioner, for his loyal co-operation. Both Commissioners had to carry out the work through a country presenting the greatest difficulties to survey operations. In some places the nearest water to the survey points was forty miles distant, and even then the supply was precarious. In others, heavy clearings of shrub and forest had to be made, and the great distances from points where repairs of waggons, &c., could be executed largely increased the difficulties.

Mr. Alexander Simms rendered most valuable service in Rhodesia, where he directed the field operations and made all the observations south of the Zambesi. During the wet weather transport was impossible, and soon after the rains ceased the natives began to burn the grass—a process that filled the air with such dense smoke that no horizontal angles could be measured. Thus the patience and endurance of the observer were most severely tried, and the greatest credit is due to Mr. Simms for the way that he stuck to his trying work and the excellent results that he secured.

To Dr. Rubin and Mr. McCaw in Northern Rhodesia a very heavy and trying task has fallen. They had to encounter similar, and even greater difficulties than those encountered by Mr. Simms—to train natives in heliograph signalling, a matter of the greatest difficulty, as natives are only willing to take short periods of service, and quit the work almost before they are trained. They have now devised simpler methods, which natives can be readily taught, and which are not liable to failure. In this and many other ways they have shown an infinity of resource in trying and difficult circumstances.

The survey owes much to the services of Mr. Robinson, who has been long at the head of the computing staff, and has raised himself by his energy and talent to that position from that of a computer at the Observatory. Mr. Lowinger has done valuable work in a like capacity.

To these men and their cordial co-operation the success of the geodetic survey is due.

I cannot conclude without an expression of regret that, on account of the present financial depression in South Africa generally, it has been found impossible to commence the topographic survey, of which the country stands so much in need and for which the geodetic survey furnishes so reliable a basis.

I cannot think that this most necessary work, for which all the preliminary arrangements have been made, can now be long delayed, and I venture to hope that the influence of the opinion of this Association may be exercised in the way of directing the attention of Ministers to the wisdom of making an early beginning of the work.

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Comparison of Measured Lengths of Bases with Lengths computed from Port Elizabeth Base.

Computed minus Measured.

——	Chain	Approx. Length of Chain	Log. Error	Feet	Ratio 1 in
		Miles			
Zwartland . .	1	500	−·0000139	−1·37	31,250
Kimberley . .	2	400	−·0000146	−0·50	29,750
	3	600	−·0000139	—	—
Kimberley . .	1+3	1,100	−·0000278	−0·94	15,620
Natal . . .	4	400	−·0000104	−0·26	41,770
Belfast . .	5	700	−·0000068	−0·98	63,870
Ottoshoop . .	6	950	−·0000143	−1·88	30,380
Kroonstad . .	7	1,050	−·0000128	−1·92	33,930
Wepener . .	8	1,200	−·0000078	−1·28	55,680
Kimberley . .	9	1,150	−·0000133	−0·45	32,650

Closure on Lines.

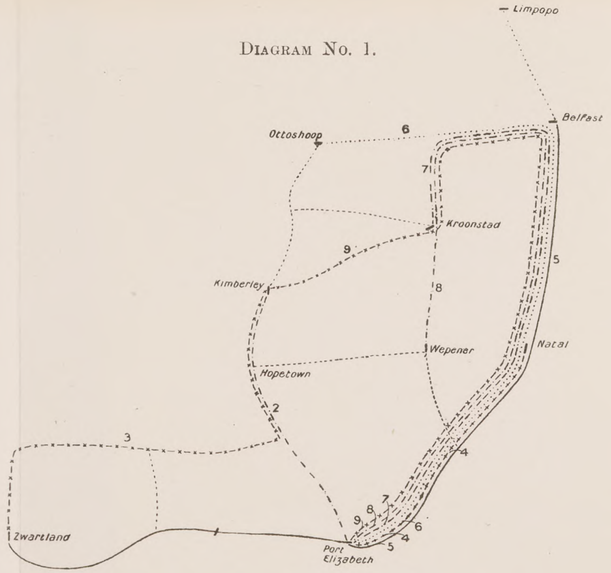
Circuit—Junction	Approx. Length	Logarithmic Discordance	Discordance in Feet	Ratio
	Miles			
1+2[1] Bruintjes Hooghte Kagaberg	1,100	·0000132	7·16	1 in 32,900
1 Bushmansberg Elandsberg	700	·0000084	3·44	1 in 51,450
7 Drakensberg Salt Lake	650	·0000010	0·28	1 in 434,300
5+7[2] Lubisi—Xuka	1,100	·0000031	1·67	1 in 140,000
3+4+5+7[3] Scholtz Kop Tarantal Kop	1,500	·0000029	0·77	1 in 150,000

[1] This is equivalent to the closure on Kimberley Base through chains 1+3 and 2. (See Diagram No. 1.)

[2] Part of the temporarily adjusted chain for the closure on Natal Base enters into this circuit.

[3] The temporarily adjusted chains for closure on Kimberley and Natal Bases enter into this circuit. Otherwise the equation would be equivalent to the closure on Kimberley Base through chains 2 and 9. (See Diagram No. 1.)

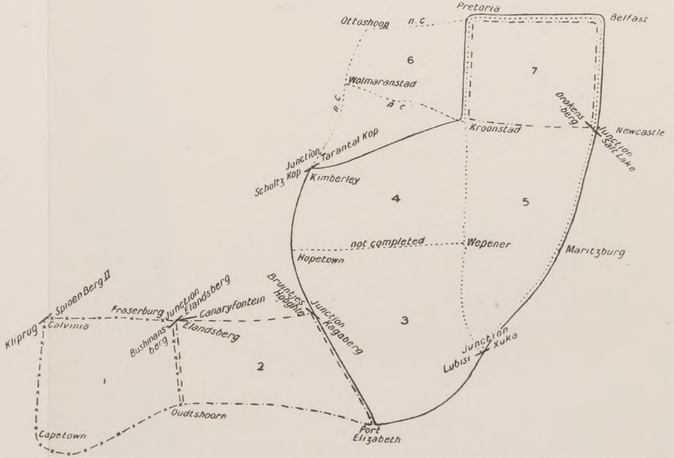
DIAGRAM NO. 1.



Comparison of Measured Lengths of Bases with Lengths computed from Belfast Base.

——	Chain	Approx. Length of Chain	Log. Error	Feet	Ratio 1 in
		Miles			
Ottoshoop . .	6−5	250	−·0000075	−0·99	57,900
Kroonstad. .	7−5	350	−·0000060	−0·90	72,380
Wepener . .	8−5	500	−·0000010	−0·16	434,300
Natal. . .	4−5	300	−·0000036	−0·09	120,600
Port Elizabeth .	−5	700	+·0000068	+0·27	63,870
Zwartland. .	1−5	1,200	−·0000071	−0·70	61,160
Zwartland. .	9−5−3	1,250	+·0000074	+0·73	58,690
Kimberley. .	9−5	450	−·0000065	−0·22	66,810
Kimberley. .	2−5	1,100	−·0000078	−0·26	55,680

DIAGRAM NO. 2.—CLOSURE OF CIRCUITS.



Closure in Latitude, Longitude and Azimuth.

ϕ = Limits of Lat. L. = Limits of Long.

Circuit 1.

Terminal Line: Kliprug—Spioenberg II.

ϕ 31° to 35°
L. 18°·5 to 22°·2

Errors	Lat.	Long.	Az.
Right-hand branch			
−Left „ „	+0″·032	+0″·165	+0″·075

Circuit 2.

Terminal Line: Canaryfontein—Elandsberg.

ϕ 31° to 34°·2
L. 22°·2 to 26°·2

Errors	Lat.	Long.	Az.
Right-hand branch			
−Left „ „	+0″·028	+0″·050	−4″·229

In Circuits 1 and 2 the errors of closure are those obtained after the adjustment for closure of bases.

Circuit 7.

Closure on Drakensberg—Salt Lake; through North, West, South, East.

ϕ 24°·7 to 28°·2
L. 27°·5 to 30°·5

Errors	Lat.	Long.	Az.
G. S. Report			
Computed	+0″·021	+0″·060	−0″·43

Circuit 5+7.

Closure on Xuka—Lubisi; through North, West, South.

ϕ 24°·7 to 31°·7
L. 27°·5 to 30°·5

Errors	Lat.	Long.	Az.
G. S. Report			
−Computed	+0″·172	+0″·120	−1″·48

Circuit 3+4+5+7.

Junction at Scholtz Kop—Tarantal Kop; from G. S. Report Drakensberg to G. S. Report Scholtz Kop.

ϕ 24°·7 to 34°·2
L. 24° to 30°·5

Errors	Lat.	Long.	Az.
G. S. Report			
−Computed	+0″·438	+0″·044	−2″·78

Errors	Lat.	Long.	Az.
ϕ 28°·2 to 34°·2, L. 24° to 27°·5 } Circuit 3+4 . .	+·266	−·076	−1·30
ϕ 28°·2 to 31°·7, L. 27°·5 to 30°·5 } Circuit 5 . .	+·151	+·060	−1·05

Illustrating Sir David Gill's Paper on the Origin and Progress of Geodetic Survey in South Africa, and of the African Arc of Meridian.

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